

# Japanese Interest in WFIRST-2.4m project

Toru Yamada (Tohoku University)  
JAXA/ISAS Science Committee  
WISH Working Group, Chair

Tohoku University: AURA international member

1. WFIRST-2.4m SDT: Japanese Interest
2. WISH: complementarity / synergy
3. Coronagraph Instruments for Extra-solar planets
4. Future prospects

# Science with Wide-Field NIR Surveys

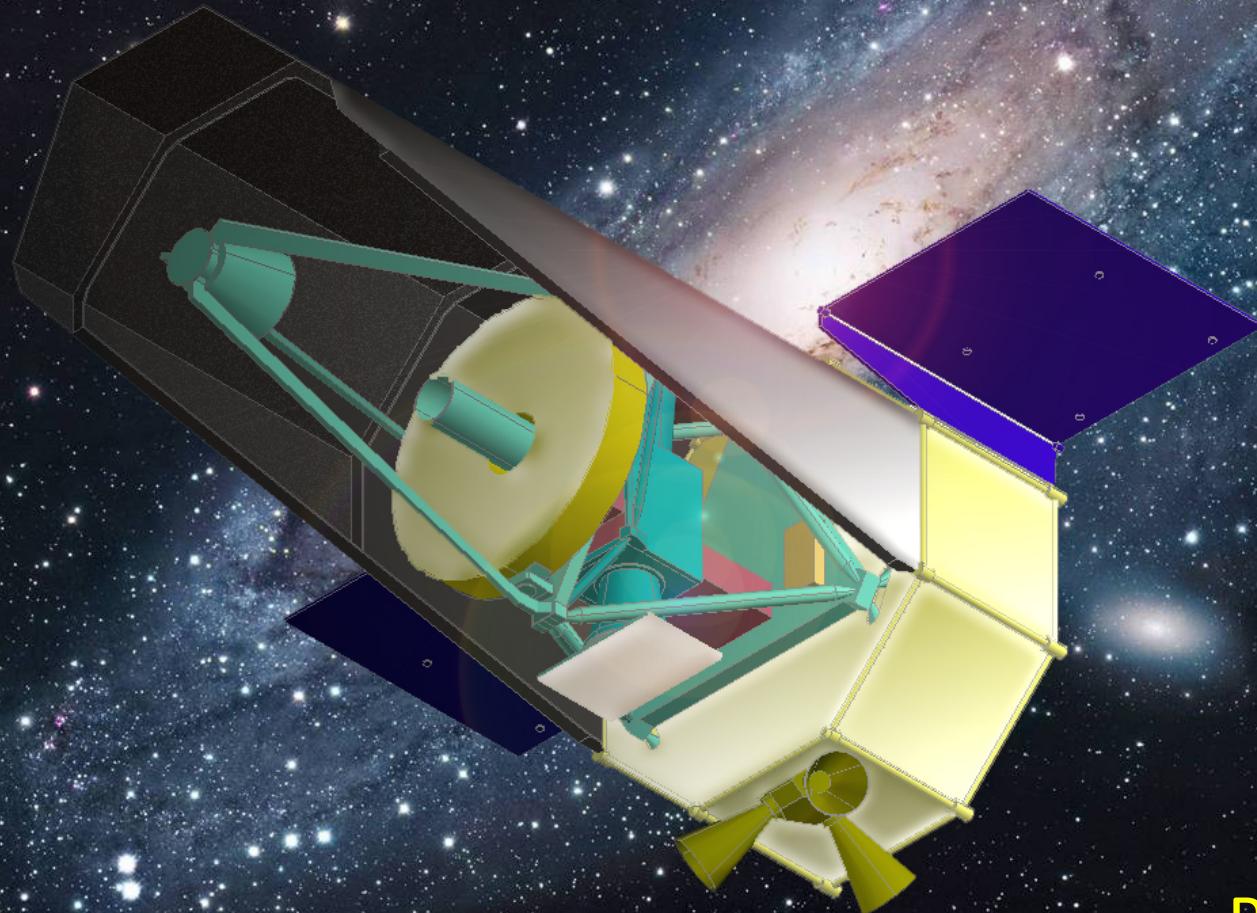
- Galaxies at z=7-15:  
Beyond the Epoch of Cosmic Reionization
- Cosmology: Dark Energy and Dark Matter
- Galaxy Formation and Evolution  
**Subaru, Akari / Subaru-HSC, PFS, TMT, WISH**
- Gravitational Lensing Extrasolar Planet Search  
**MOA, IRSF    T. Sumi contributed in WFIRST-SDT**
- Galactic Bulge: astrometry, stellar population  
**JASMINE**

# Coronagraph Instruments

- Coronagraph instruments for Subaru Telescope  
CIAO + AO36  
HiCIAO + AO188: **SEEDS** project (Tamura et al.)
- Development for future ground-based  
and space-mission coronagraph instruments  
**SITE** for TMT (Matsuo, T. et al.)  
**SCI** for SPICA (Enya et al, @ mid-infrared)
- Development for various Coronagraph Architectures
  - Phase-mask coronagraphs (focal plane mask)
  - Common-path visible nulling coronagraphs
  - Binary pupil masks
  - Pupil Remapping Interferometer
  - Unbalanced nulling interferometer

1. WFIRST-2.4m SDT: Japanese Interest
2. WISH: complementarity and synergy
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# Wide-field Imaging Surveyor for High-redshift WISH space telescope project



PI: Toru Yamada

# WISH

Concept developed for the next JAXA/ISAS M/L-class Mission  
WISH Working Group **2008 Sept-** (Chair, Yamada)

## Science Goals

- Explore the universe beyond Cosmic Reionization :  
    Studying the earliest galaxy formation at  $z=8-15$
- Cosmic Expansion History with SNIa (type Ia Supernovae)  
    NIR detection and light curves of SNIa at  $z=0-2$
- Deep and Wide-field NIR Survey at  $1-5\mu\text{m}$   
    Various fields in astronomy

## Key Features

- Dedicated deep and wide-field imaging surveys at  **$1-5\mu\text{m}$**
- Survey strategy: **100deg $^2$ , 28AB (5 $\sigma$ )**, 6 broad bands (main survey)

## Base Design Model

- 1.5m light-weighted glass primary mirror
- CFRP structure @90-100K
- Diffraction limited image at 1-5μm over the flat focal plane
- H2RG 32x2kx2k 128Mpix
- 0.155"/pixel(18μm-pitch), 850arcmin<sup>2</sup>/FoV
- Light weight: 1.4t (WET)

## Current Status

- JAXA/ISAS WISH Working Group since 2008 (pre Phase A)
- More than 20 astronomers/engineers have been working for R&D
- JAXA/ISAS R&D budget (~1M\$, without including man power cost)
- WISH Mission Proposal Draft distributed (500pages, in Japanese, 2012)
- Potential international Partners: SAO (USA), LAM (France), Canada
- Proposed Schedule: 2013 Mission Definition Review,  
2015 System Definition Review, Launch by 2020
- Expected Cost (w/o launch, operation, data facility) : 250-300M\$

## US-collaboration

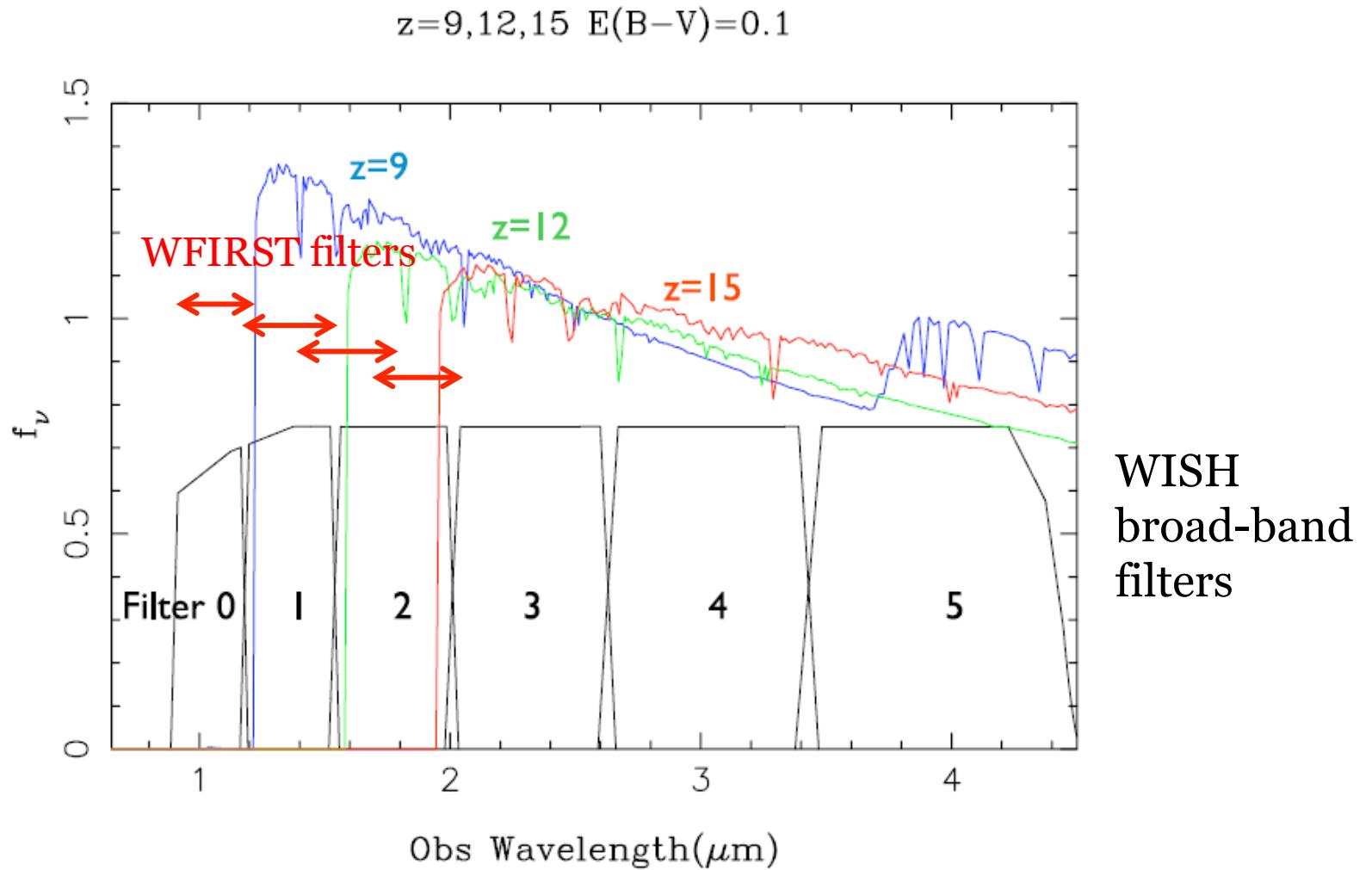
- Proposal submitted for NASA SALMON2 MoO  
(PI: G. Fazio, Smithsonian Astrophysical Observatory)
- Testing and Providing Focal Plane Arrays / ASIC electronics

## France-collaboration

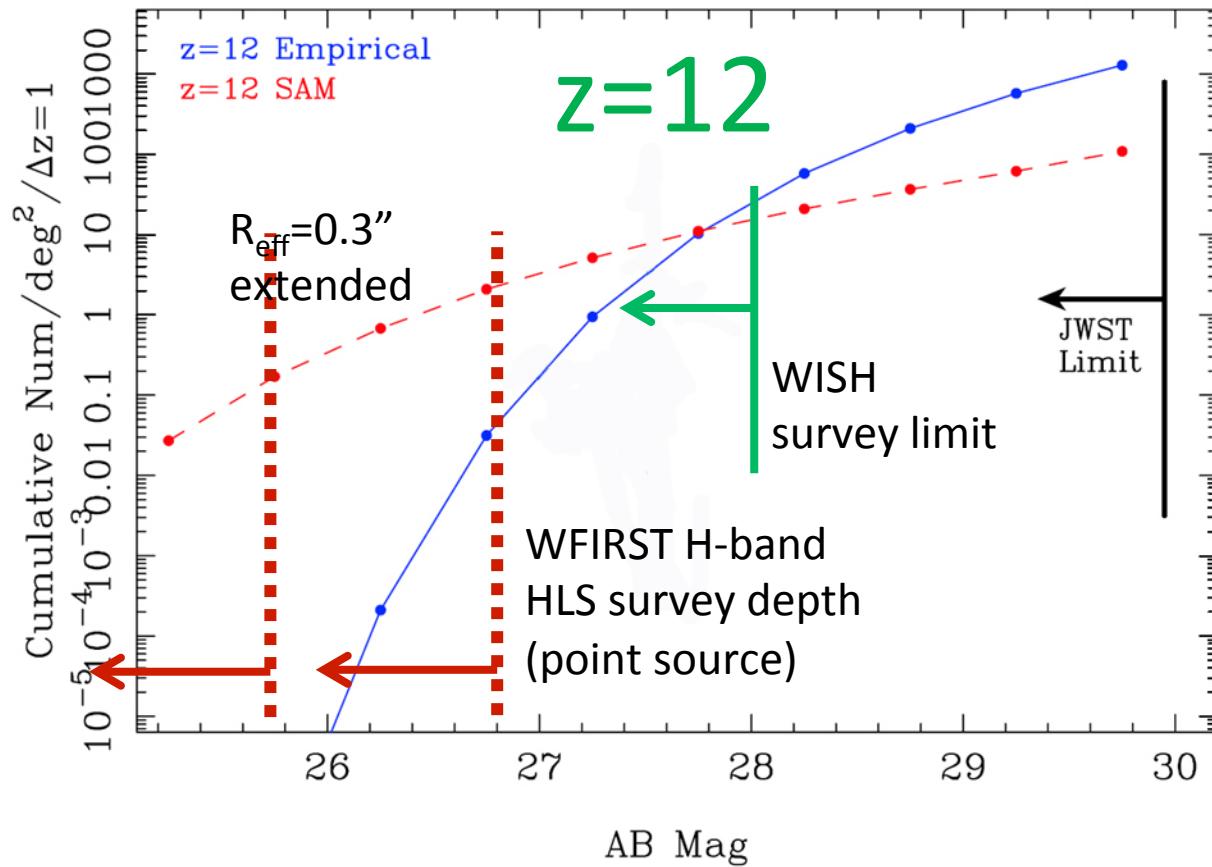
- Proposal Submitted for CNES Missions of Opportunity Program
- IFU Spectrograph as an optional instrument
- French internal WISH workshop at IAP (Oct 3)

and Canada, ...

# Extremely High-Redshift Galaxies: First Billion Years



# In the observers' frame...



Limit of  
AB>28 is  
needed

Empirical  
luminosity evolution

Semi-analytic  
Model prediction

FoV JWST NIRCam 2.2'x2.2' x 2ch (per filter)  
 $\sim 2.8 \times 10^{-3} \text{ deg}^2$

# For the Science Cases of the 1<sup>st</sup> Billion Years

- 250K (2.4μm cut) is very desirable, otherwise, not much gain from WFC3 results except for the survey volume.
- Additional Survey Strategy,  
~100 deg<sup>2</sup>, ~28AB ZYJHK is desirable
  - O(10<sup>4</sup>) z~8-12 objects are detected
  - needs at least ~1 year for ~100 deg<sup>2</sup>  
~0.5 ~50
- Narrow/Intermediate-band filters?

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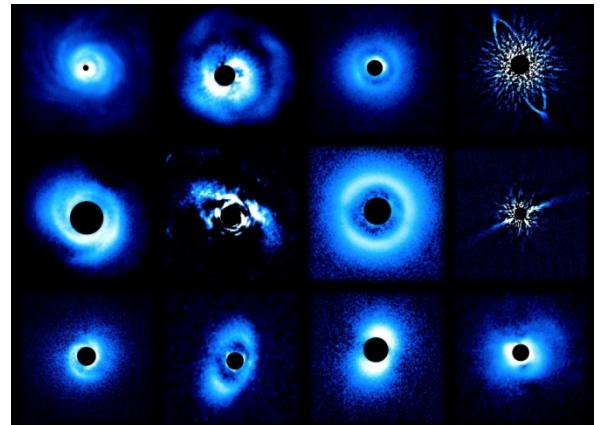
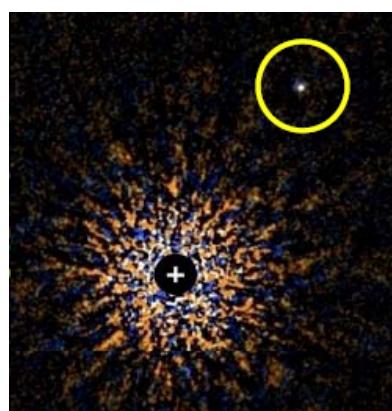
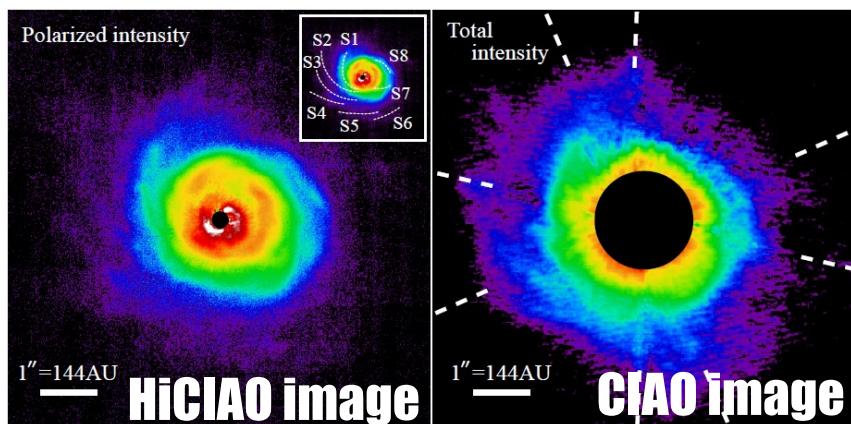
# Subaru 8.2-m telescope has had several “Planet & Disk Finders” from its early phase to present

## ★ CIAO (Coronagraphic Imager with Adaptive Optics)

- ★ Operation years: 2001 - 2008
- ★ Cold Coronagraph + AO36; w/ 1024x1024 InSb array (Raytheon ALLADDIN)
- ★ Large disks (e.g., *AB Aur*), circumbinary disks (e.g., *SR24*), massive YSO disks (e.g., *BM*)
- ★ Very wide orbit planets (*DH Tau b*, *GQ Lup b*)

## ★ HiCIAO (High Contrast Instrument for next generation AO)

- ★ Operation years: 2009 -
- ★ Warm Coronagraph + AO188 / SCExAO1024 + various differential imaging (PDI, SDI, ADI)
- ★ w/ 2048x2048 HgCdTe (H2RG) array + ASIC SIDECAR
- ★ Giant planets/companions in wide orbits (*GJ 504 b*, *kappa And b*, *GJ 758 b*)
- ★ Solar-system-scale disks (gaps and spirals)
- ★ SEEDS strategic survey project ongoing

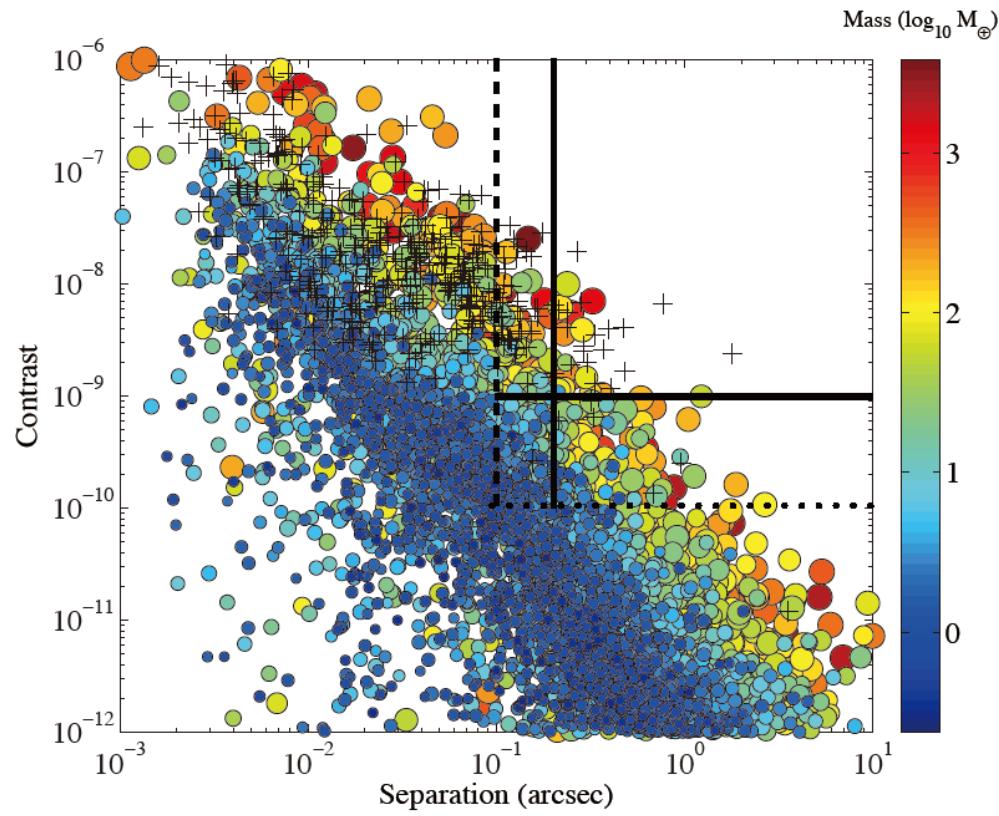


# Instrument & R&D Programs

- Subaru
  - SCExAO (Guyon), IRD (Tamura), CHARIS (Kasdin) [so far, HiCIAO, etc.]
- TMT
  - SEIT (Matsuo)
- J-TPF R&D
  - Coronagraphs (Hokkaido-Murakami, NAOJ-Nishikawa, TAUT-Kurokawa/Tavrov)
- SPICA
  - Coronagraph-Enya

# Science Threshold for WFIRST-2.4m

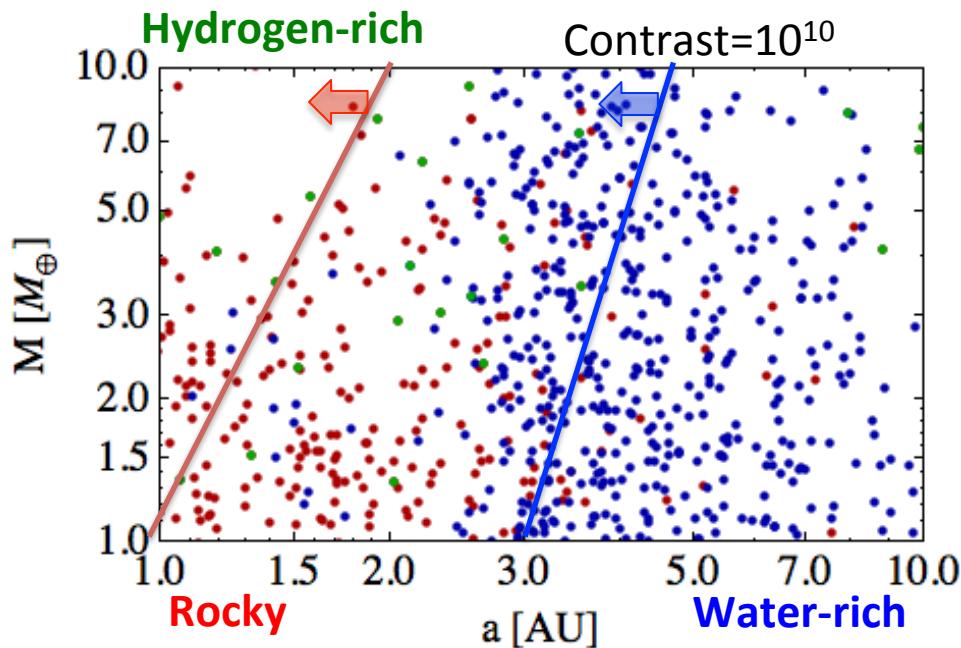
Full success : characterization of nearby Jovian Planets  
Extra success: characterization of superearth planets



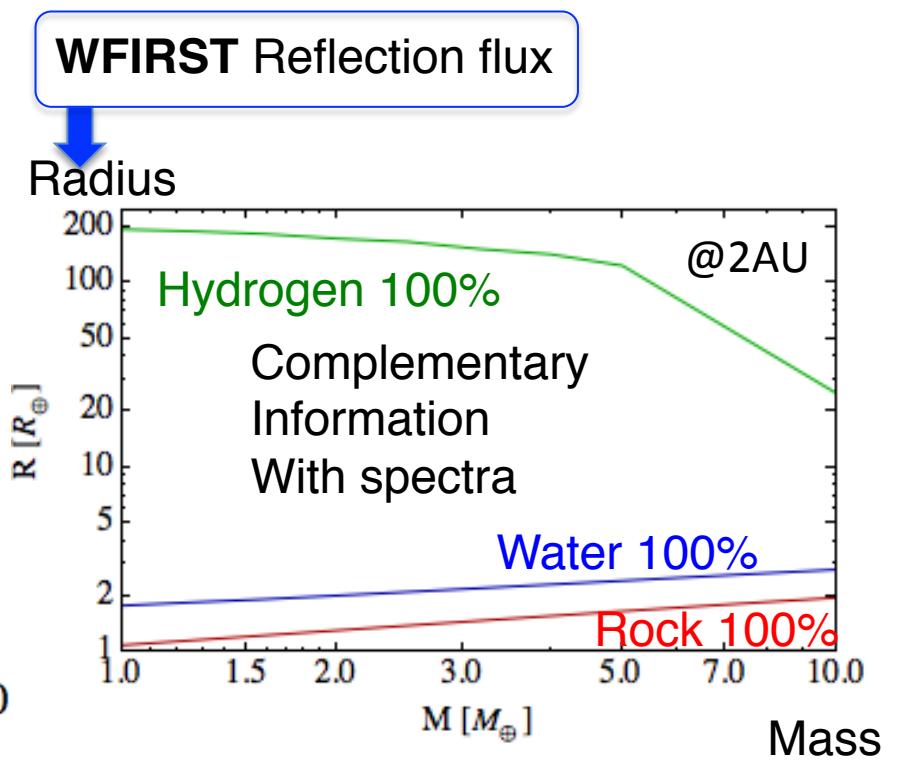
# Constraints on Formation and Compositions of Super Earths by WFIRST

## Mass-Radius Relation of Super Earths as a function of Compositions

### Prediction from Formation Theory of Super Earths



Y. Hori et al. in prep



RV follow-up  $M_p \sin i$   
WFIRST inclination

Courtesy of K. Kurosaki

# **Development for various Coronagraph Architectures**

**- Phase-mask coronagraphs (focal plane mask)**

**N. Murakami**

**- Common-path visible nulling coronagraphs**

**SPLINE N. Murakami**

**- Pupil Remapping Interferometer**

**T. Kotani**

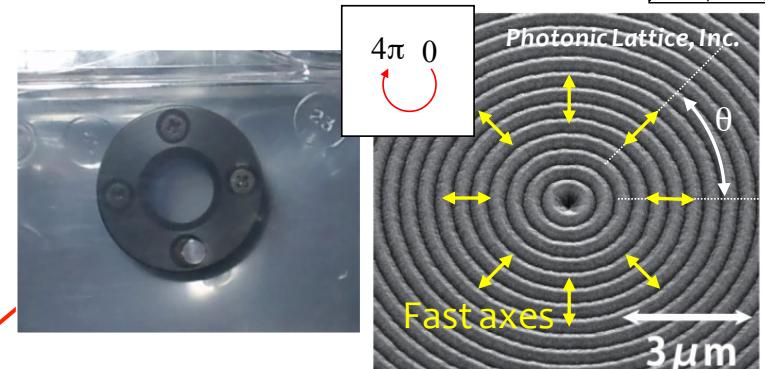
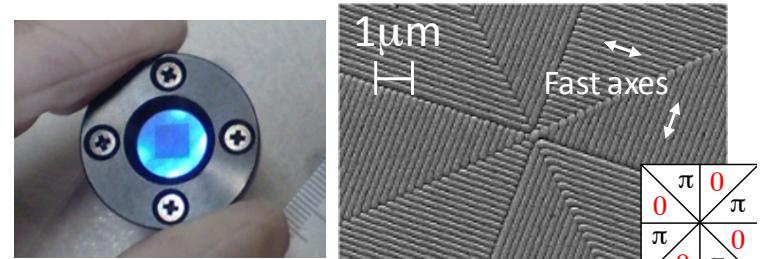
**- Unbalanced nulling interferometer J.Nishikawa**

**- Binary pupil masks**

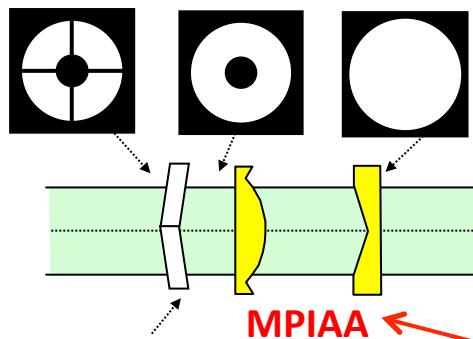
**SPICA Coronagraph Instrument K.Enya**

# Phase-mask coronagraphs

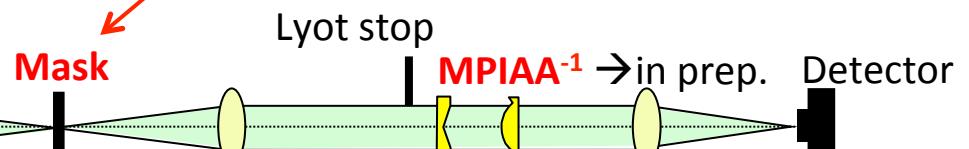
- Photonic-crystal masks (8OPM & Vortex)
  - $\sim 2 \times 10^{-8}$  contrast at HCIT/JPL (8OPM)
- MPIAA lenses (Secondary-mirror remover)
- Planned to be installed into SCExAO/Subaru



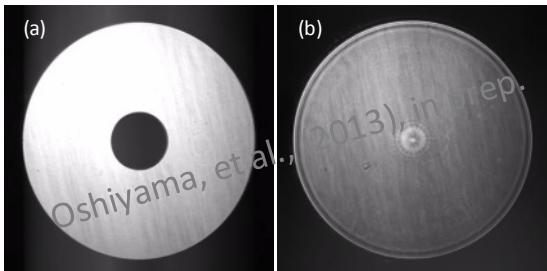
(↓) Optical setup of 8OPM/SCExAO



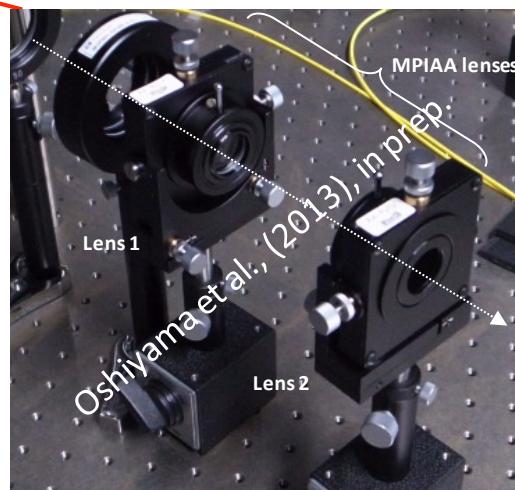
(→) Photonic-crystal vector vortex mask and 8OPM (Murakami et al. 2010, 2013)



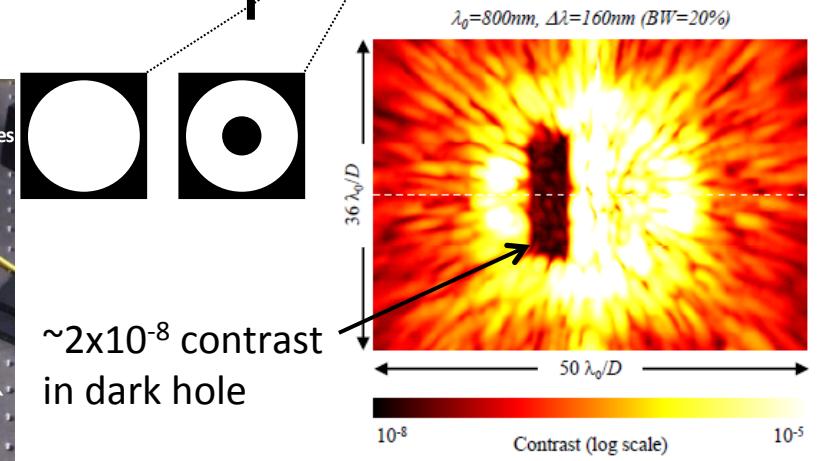
SRP: Lozi et al. 2009,  
(or ACAD: Pueyo et al. 2012)



(→) Manufactured MPIAA lenses, and  
(↑) lab. experiment of removal of a  
shade of a secondary mirror.



$\sim 2 \times 10^{-8}$  contrast  
in dark hole



(→) Lab. experiments of 8OPM with a circular pupil at HCIT/JPL (Murakami et al. 2012).

# **Development for various Coronagraph Architectures**

- Phase-mask coronagraphs (focal plane mask)  
**N. Murakami**

- Common-path visible nulling coronagraphs  
**SPLINE N. Murakami / T. Matsuo**

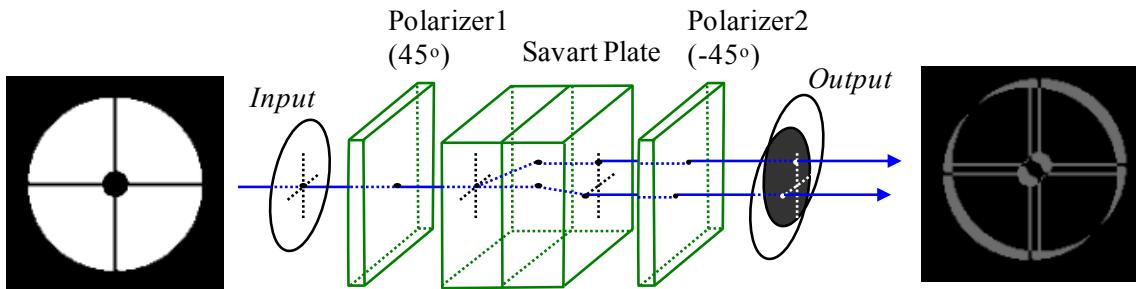
- Pupil Remapping Interferometer  
**T. Kotani**

- Unbalanced nulling interferometer **J.Nishikawa**

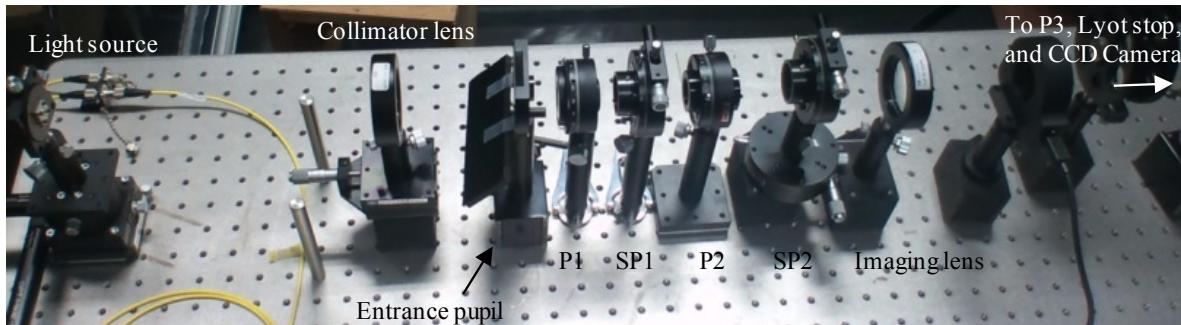
- Binary pupil masks  
**SPICA Coronagraph Instrument K.Enya**

# SPLINE (Savart-Plate Lateral-shearing Interferometric Nuller for Exoplanets)

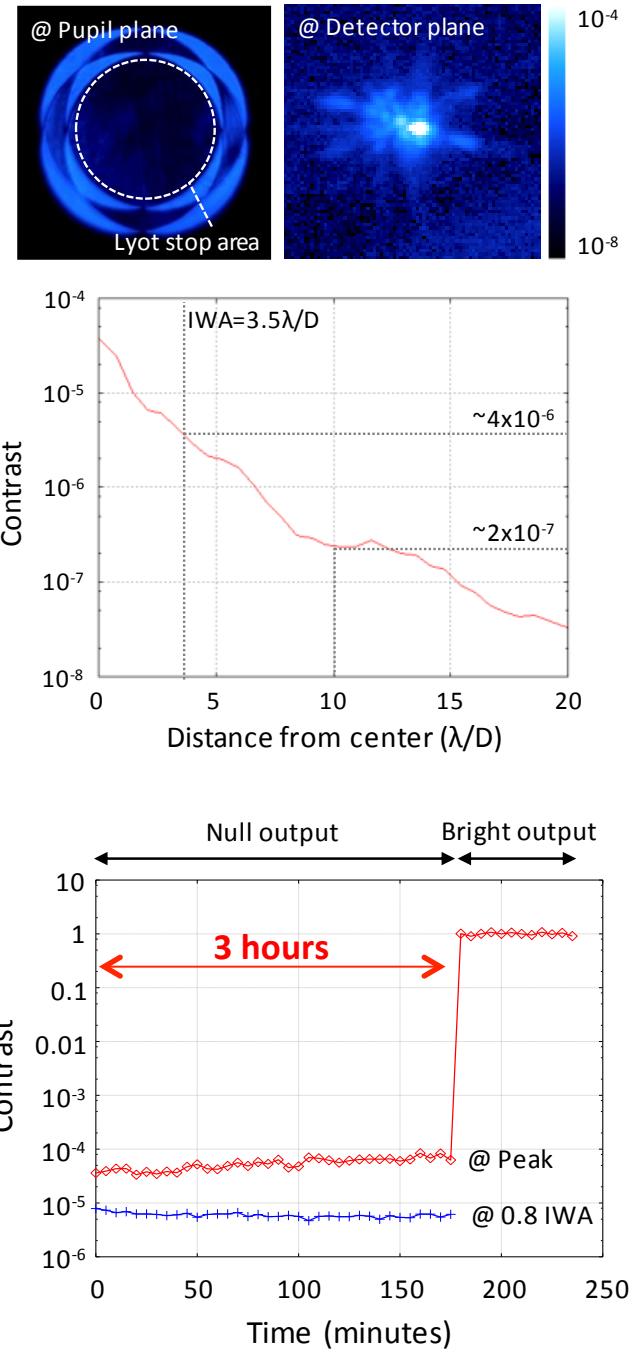
- Common-path visible nulling coronagraph (VNC)
- Simple, stable, achromatic, and insensitive to pupil geometry
- Broadband lab. demonstration of 4-beam SPLINE (Bandwidth $\sim$ 25%)
- 2-channel design for higher throughput (in prep.)



(↑) Optical setup of a 2-beam SPLINE (Murakami & Baba 2010).

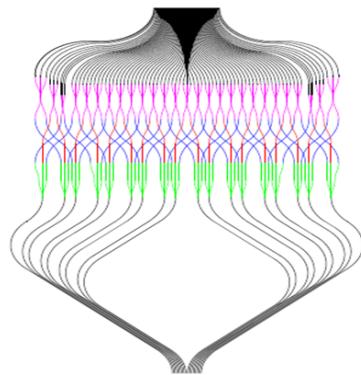
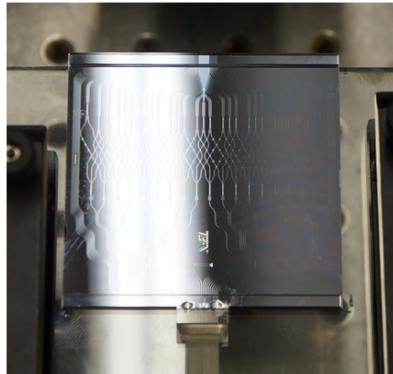


(↑) A picture and (→) lab. experiments (contrast and stability) of a 4-beam SPLINE (Murakami et al. 2012).

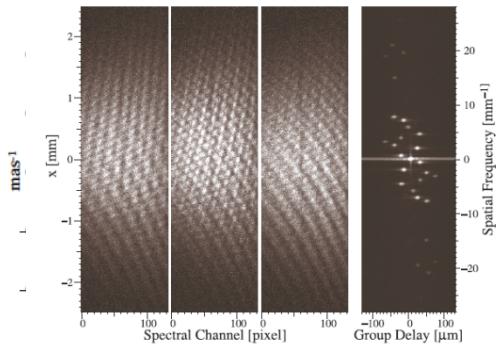
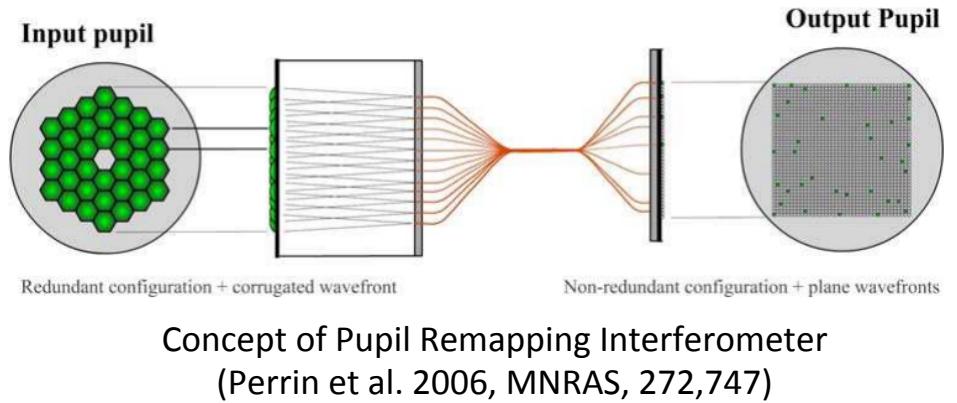


# Pupil Remapping Interferometer

- Pupil Remapping Interferometer (PRI) is an interferometric high-angular resolution and high-contrast imaging technique (Perrin et al. 2006, MNRAS, 272,747).
- PRI can measure wavefront errors of incoming light very precisely and **PRI will act as if an extreme adaptive optics but no active mechanism is required, which is a large advantage for space instruments.**



Integrated Optics Beam-combiner developed at NAOJ



Interferometric fringes obtained at Lick 3-m telescope

On-sky test of the PRI instrument at Lick 3m telescope and Subaru telescope was successfully done. It is an important step toward high-contrast imaging for the future space mission

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**SPLINE N. Murakami / T. Matsuo**

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**- Unbalanced nulling interferometer J. Nishikawa**

- Binary pupil masks

**SPICA Coronagraph Instrument K. Enya**

## ◆ High-Contrast Techniques (Nishikawa et al.)

➤ **UNI** (unbalanced nulling interferometer) (Yokochi et al. 2011 Opt Exp, Nishikawa et al. 2008 A&A)

Pre-nuller for Dynamic Range Enhancement

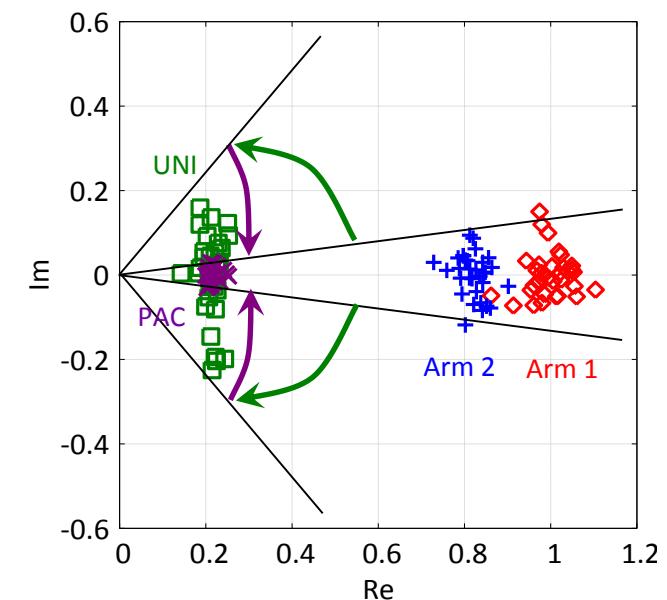
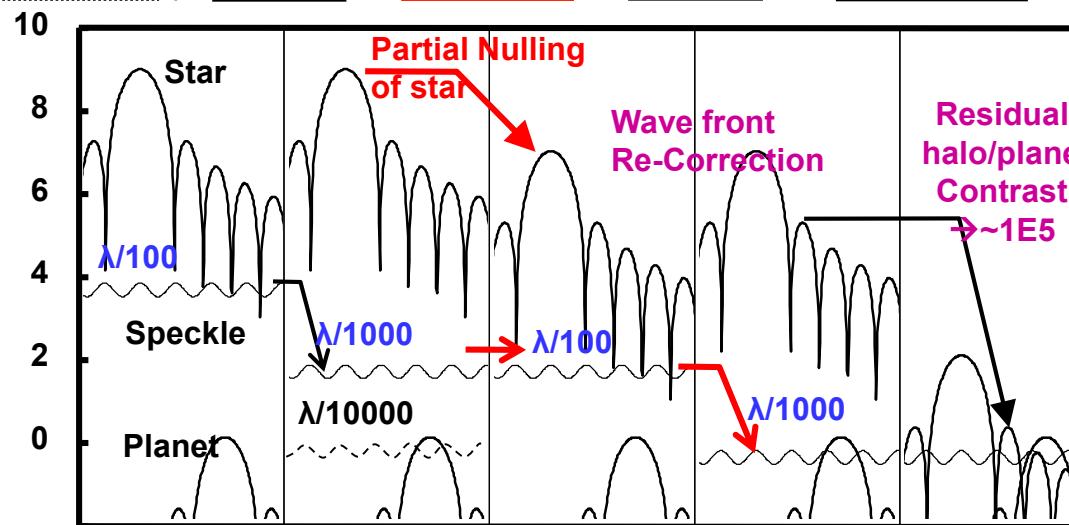
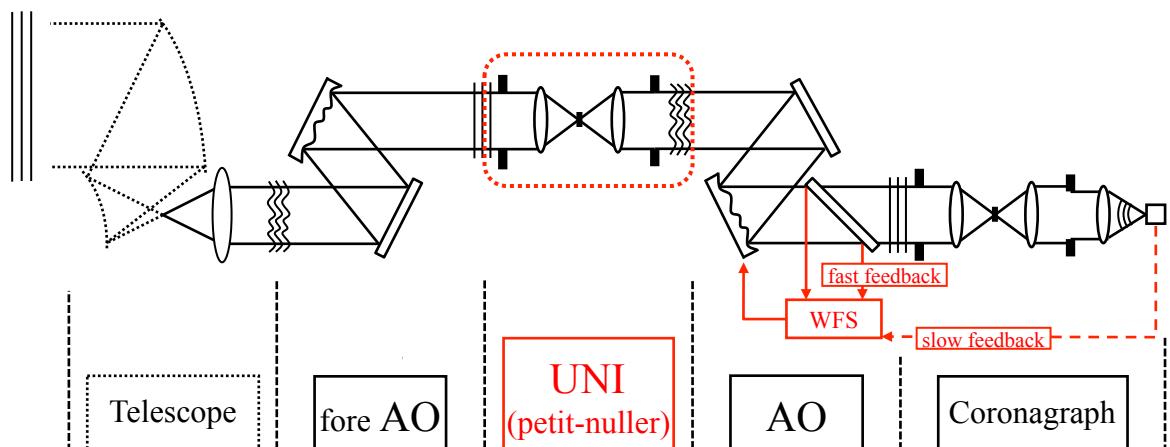
Principle was confirmed by experiments

➤ **Dual-feedback** control method

(Ohya et al. 2012 SPIE)

Under development

Pupil-plane WFS (fast feedback) + focal-plane wavefront sensing (slow feedback)

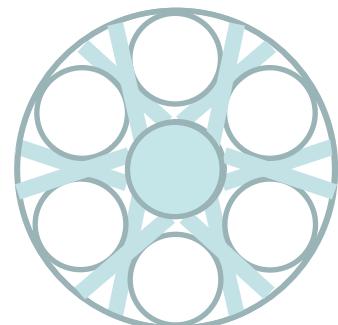
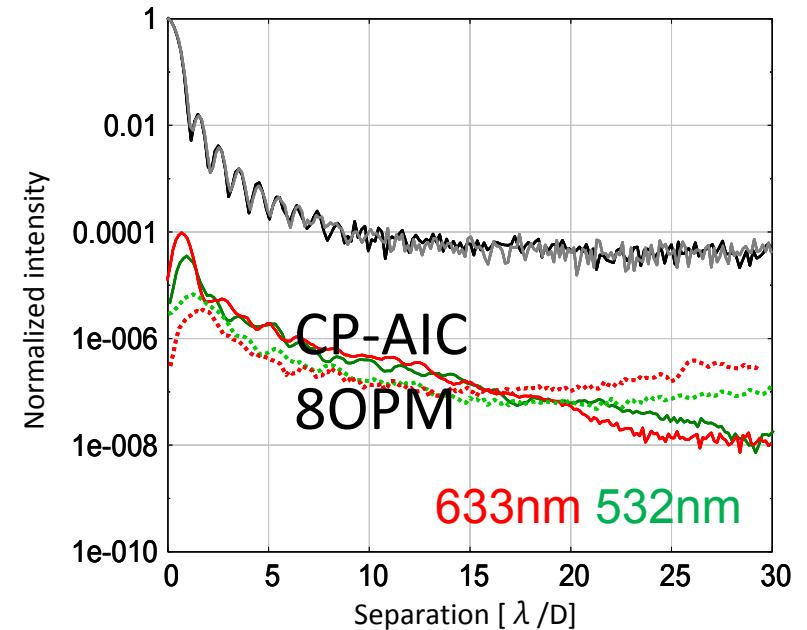
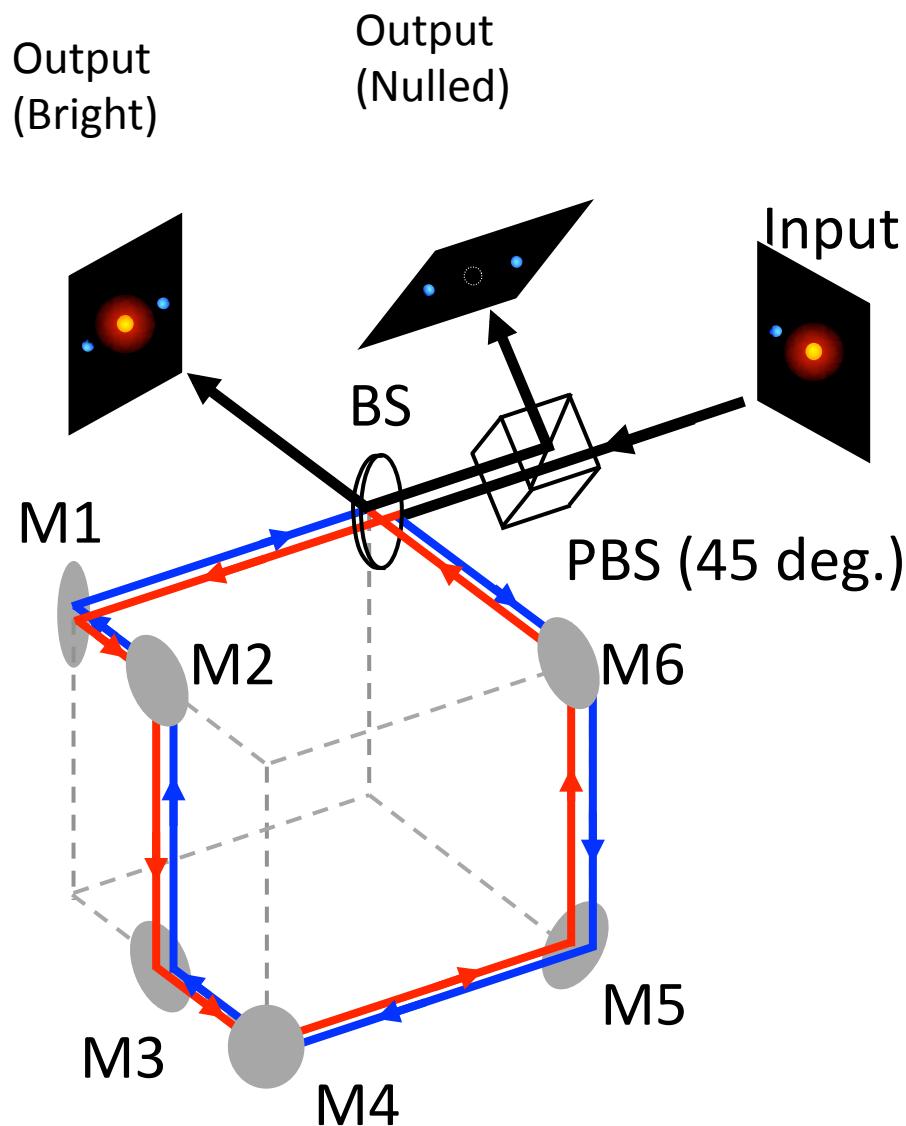


Yokochi et al. 2011.  
Extra-reduction of wavefront-error energy after UNI and AO (PAC) having the same amount of phase error.

## ◆ Coronagraph Technique

- *Common-Path AIC (3D Sagnac Interferometer)*
- Pupil-rotation Nulling Coronagraph

(Tavrov et al. 2008, Yokochi et al. 2009 )



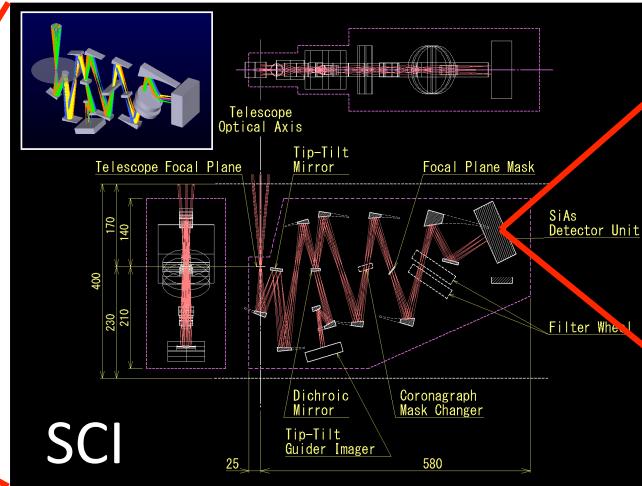
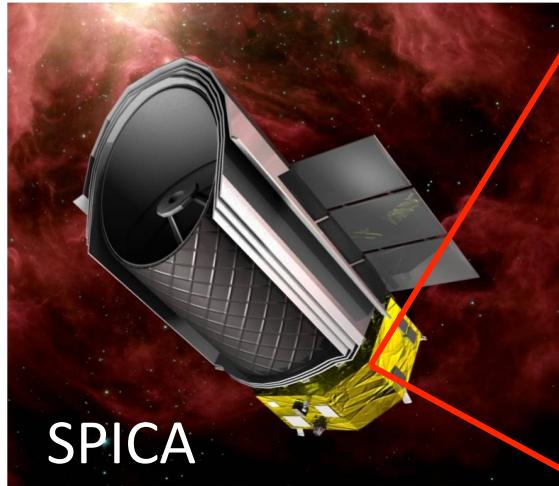
Clear aperture  
at 180deg rotation

# **Development for various Coronagraph Architectures**

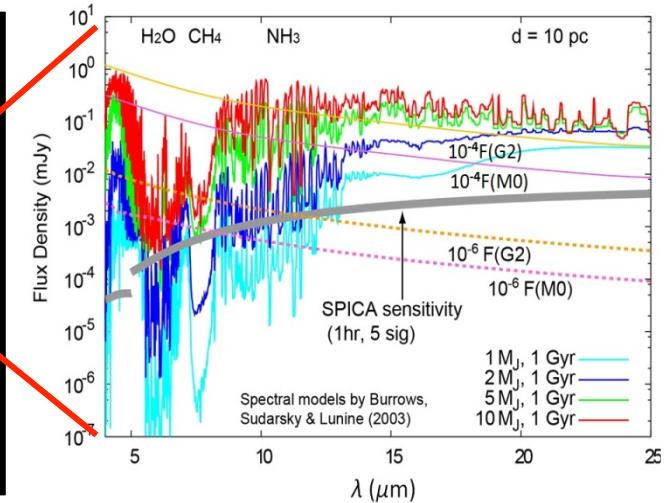
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**SPICA Coronagraph Instrument K. Enya**

# SPICA Coronagraph



Burrows et al. 2003

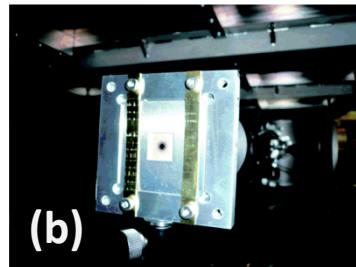


The SPICA coronagraph team  
(Document preparation: K. Enya)

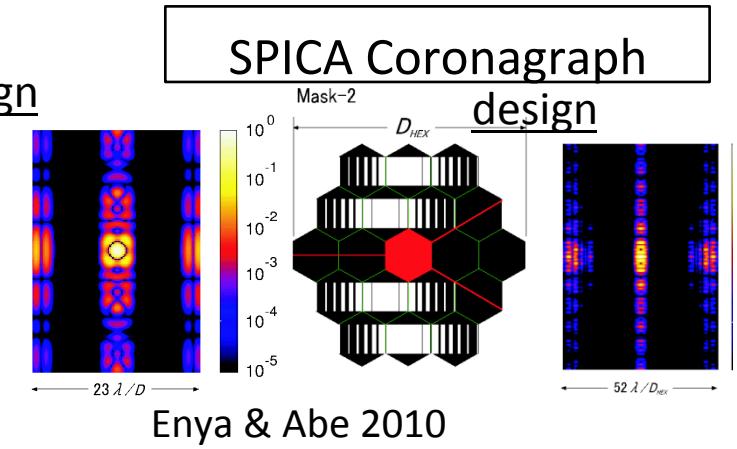
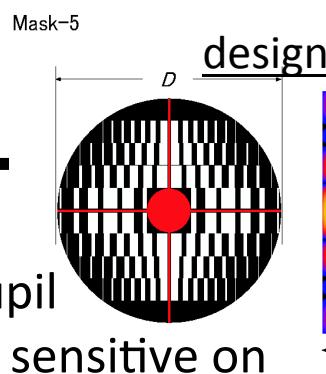
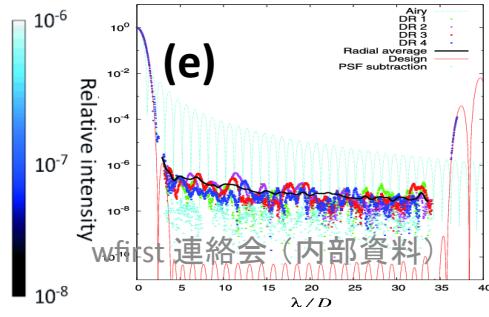
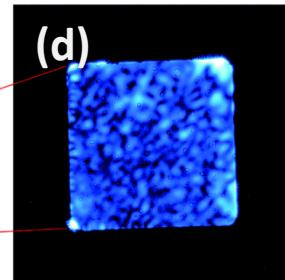
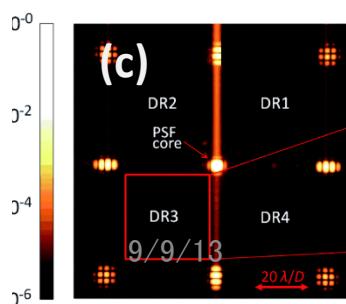
- SPICA: astronomical space observatory mission with 3m class cryogenic (6K) telescope (e.g., Nakagawa et al. 2013)
- The SCI: the SPICA Coronagraph Instrument. Coronagraphic spectroscopy in MIR is unique (e.g., Enya, Kaneda, Kotani et al. 2013)

# Developments for coronagraph(1/2)

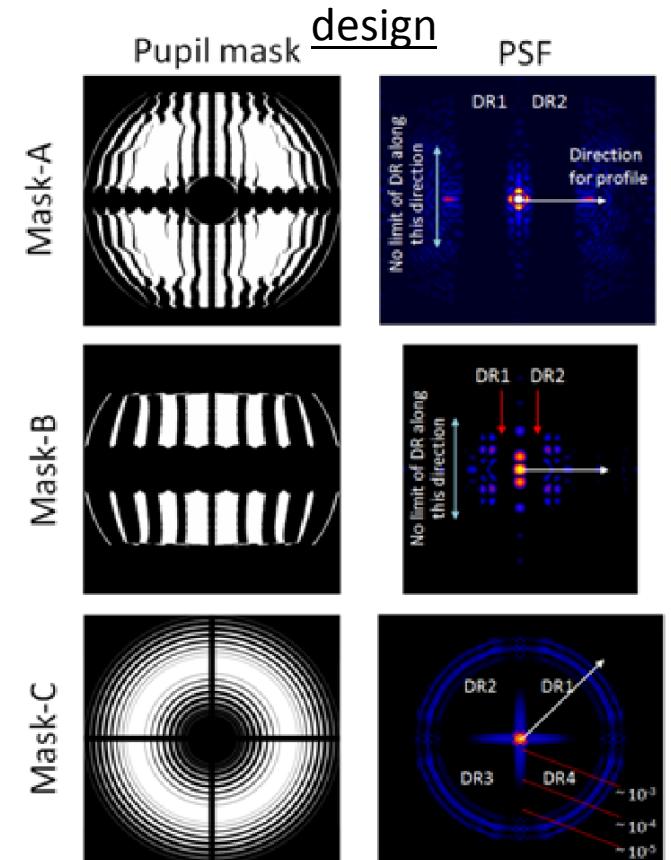
- Design
  - Binary pupil masks for obscured pupil
  - Advantages: wide IR coverage, less sensitive on telescope pointing error, simple optics
- Laboratory experiment
  - (a) Precise masks on glass substrate by electron beam lithography
  - (b) Free-standing masks (i.e., no substrate)
  - (c)-(e) High contrast is demonstrated at visible wavelength (e.g., Haze et al.2011, enya et al. 2007)



experiments



Enya & Abe 2010

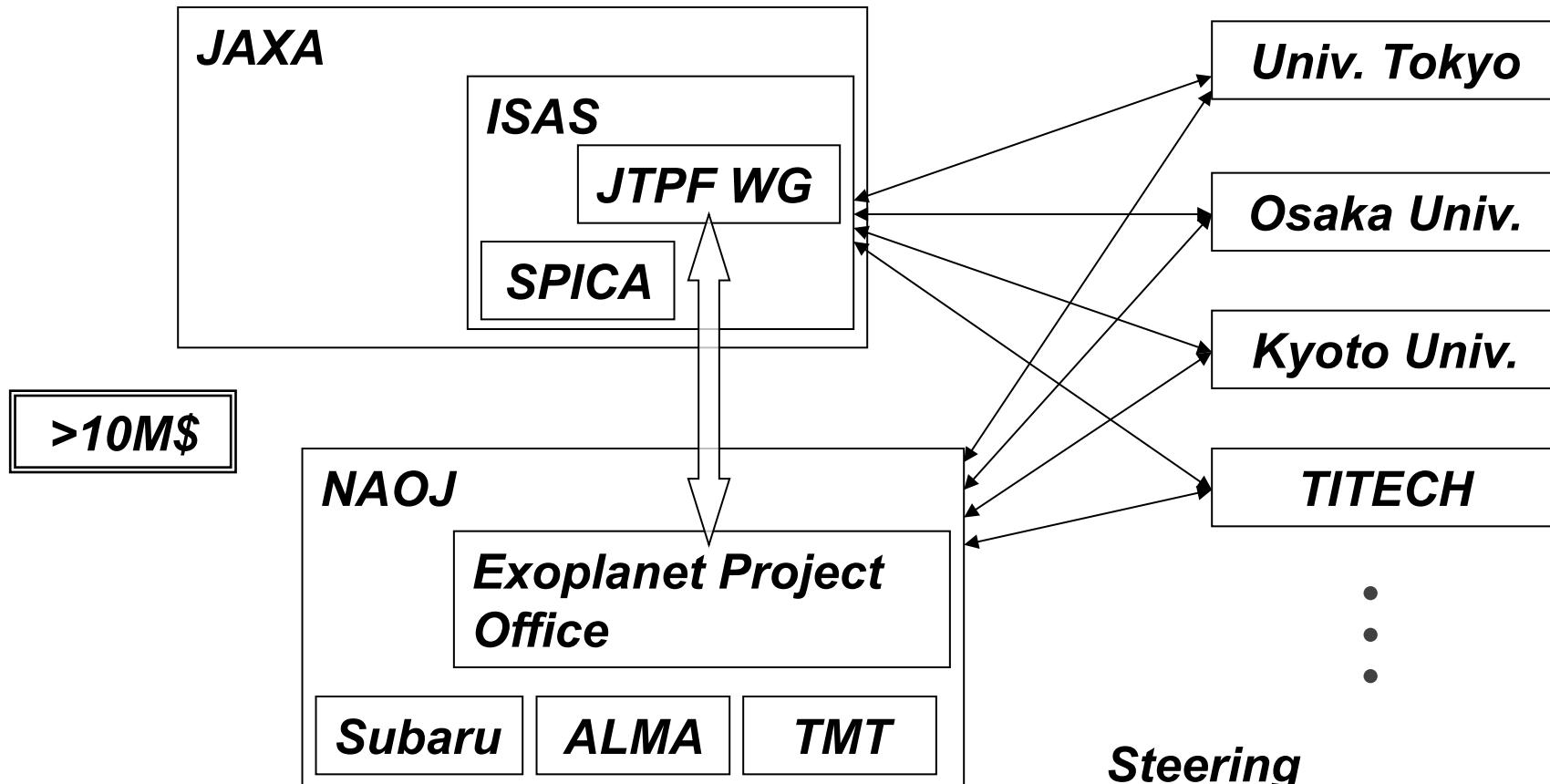


Enya et al.2011

(\* Based on LOQO: Vandervei 1999)

# Organizations in Japan (on exoplanets)

<10M\$



*ISAS & NAOJ are National Agencies for Big Projects Joined by University Researchers*

*Steering  
Participating to Projects  
Using Science Data  
Exchange of People*

# Potential Japanese Contribution/Initiative in wfirst-2.4m Project

## - **Science**

“first billion yeas” (WISH, Subaru)

extrasolar planets (microlensing, superearth models, SEEDS)

survey design (e.g., optimization for microlensing)

## - **Development (hardware)**

Telescope or Spacecraft module /

Instrument / Detector on-sky testing /

Coronagraph development

## - Data Management

Coordination with Subaru HSC/PFS optical  
observations for northern sky

## People involved in the early discussion:

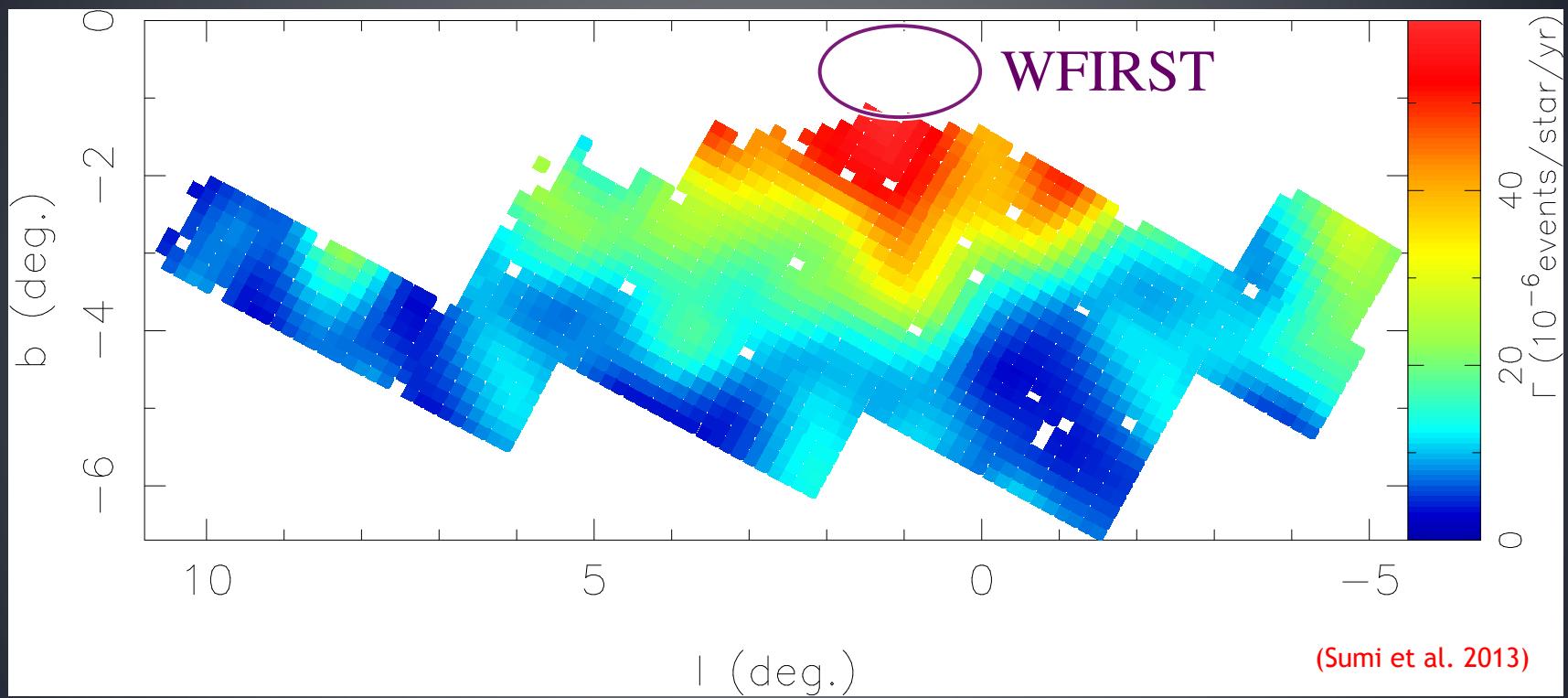
Gouda, N. (NAOJ), Iwata, I. (NAOJ/Subaru),  
Kawai, N. (TiTech), Kodama, T. (NAOJ),  
Miyazaki, S. (NAOJ), Morokuma, T. (Tokyo)  
Nakagawa, T. (ISAS)  
Shibai, H. (Osaka), Sumi, T. (Osaka),  
Takada, M. (IPMU), Tamura, M. (Tokyo/NAOJ),  
Yamada, Y. (Kyoto), Yamada, T. (Tohoku), Yano, T. (NAOJ)  
**(WISH, JTPF, JASMINE, Subaru-Euclid ,,,)**

## Coronagraph:

Enya, K., Kotani, T., Kawahara, H. , Murakami, N., Nishikawa, J.

.. and more...

# Optimize observation fields by mapping the microlensing event rate

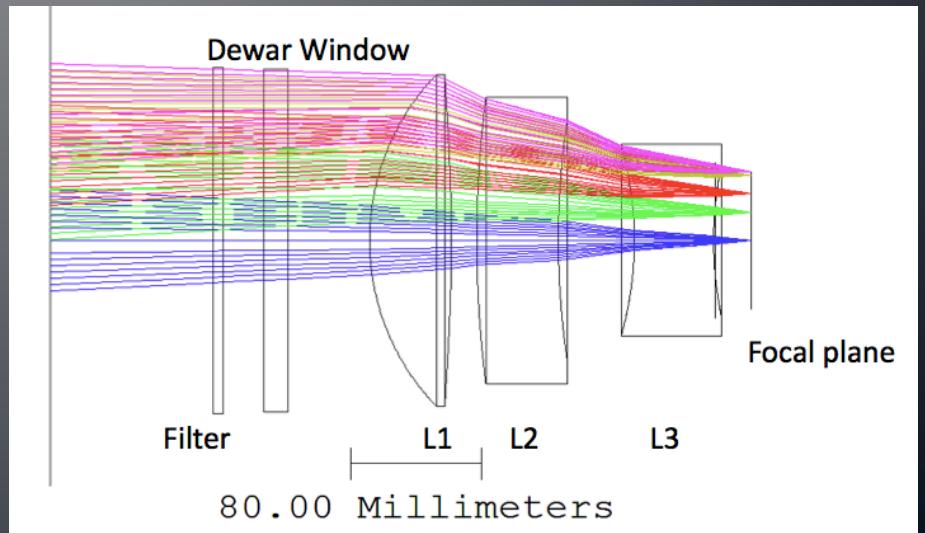
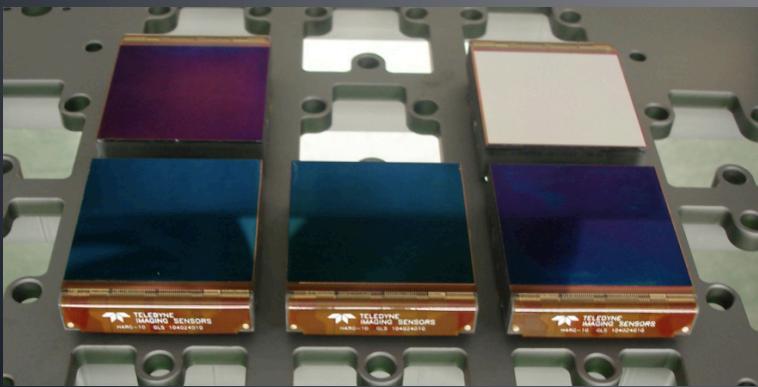
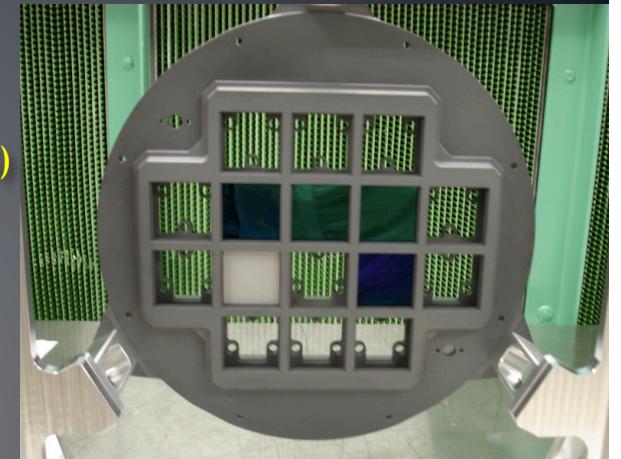


Peak at  $l=1^\circ$

1.6X higher rate than SDT report.

# IR survey with existing four H4RGs

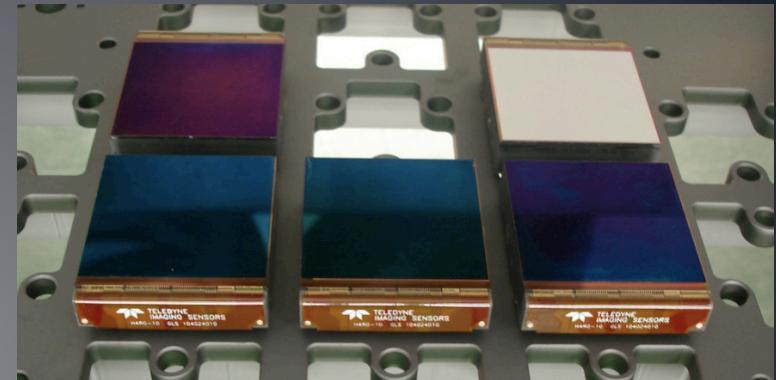
- Four H4RGs, Dewar, electronics are ready
- New 1.8m IR telescope in Namibia
- WiFCOS camera for IRSF (with R.Barry at GSFS)
  - Need focal reducer optics
    - ◊ Focal Length: 13.8m → 6.61m
    - ◊ Pixel scale: 0.45"/pixel → 0.312"/pixel
    - ◊ FOV: 7.7' → 45'
  - Filter systems (J,H,K,narrow-band, polarization filter? )



# Possible contribution to WFIRST from Japan

## Hardware:

- Flight calibration system
- Integral field spectrograph
- Fine guidance sensor
- Coronagraph
- H4RG development by ground base IR telescope  
→ long-term characterization



4kx4k H4RG

## Non-Hardware

- Data from a wide-area sky survey by Subaru HSC, designed to complement the WFIRST observing program
- Data processing and archiving
- Optimize the WFIRST fields by ground base IR telescope